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EDITOR'S COMMENTS

Herein is the 2017 Fall issue of the *Journal*. This is an exciting time for science. Studies of the brain are providing new insights into human behavior. Recently the Laser Interferometer Gravitational Wave Observatory (LIGO) has measured black hole collisions. I hope that our readers will contribute papers on these topics.

For this issue we have two quite different papers. One is an interesting study on raindrops. Have you ever wondered how wet you get when running in the rain? The other reports on the discovery of a new genus. It comes from colleagues in India. This is their second report of a discovery in our *Journal*.

Letters to the editor are encouraged. Please send email (wasjournal@washacadsci.org) comments on papers, suggestions for articles, and ideas for what you would like to see in the *Journal*. We are a peer reviewed journal and need volunteer reviewers. If you would like to be on our reviewer list please send email to the above address and include your specialty.

The sciences remain at the forefront of human progress. This *Journal* contributes to that effort. Without an extensive variation in what we study we step backward. One never can tell what useful result will come from an otherwise rare study. I offer one example. Many years ago there was a scientist who studied slugs found on the Massachusetts shoreline. His interest was only the slugs. The fact that slugs seemed to have a method of controlling bleeding was a side interest. When this odd result was discovered by medical researchers they found a solution to a long standing medical problem: hemophilia. Such a result cannot be predicted. Science must wander where it will. Out of those wanderings come solutions to today and tomorrows' problems.

Sethanne Howard

Journal of the Washington Academy of Sciences

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HOW WET DO YOU GET IN THE RAIN, IF YOU DON'T CARE HOW WET YOU GET?

Water absorption by walkers and runners indifferent to precipitation

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Abstract

Many researchers have discussed the optimum speed at which to walk in the rain to get the least wet. This article looks at a related problem: if walkers or runners are indifferent to the rain, how drenched do they become during their journeys home? The semi-empirical answer employs basic introductory physics and biomechanics, as well as anthropometric formulas related to human-body ratios.

Introduction

A VENERABLE PROBLEM in applied mathematics and physics is to answer the question "How fast should you walk in the rain to get the least wet?" Many articles address this subject — and variations thereof — for a variety of audiences. Early papers were aimed mostly at a mathematical audience.[1,2,3] The typical result is that if the rain is at the walker's back, then the walker's optimal speed equals the rain speed. In any other situation, the walker should go as fast as possible.[4] Others explored related topics. The pseudonymous Hailman and Torrents looked at the effect of ellipsoidal walkers[5] while Banks allowed for splashing from the sidewalk.[6] As befits meteorologists, Holden *et al.* included discussion of the rate of rainfall,[7] as did Peterson and Wallis.[8] Stern discusses the effect of raindrop sizes and vertical motion of the walker.[9] Bocci approached the question as a pedagogical means to demonstrate fluxes and flux densities in physics.[10] Mungan and Lipscombe devised a simple cart propelled by rain power alone.[11]

The classical Hollywood musical *Singin' in the Rain* suggests a related question. After working all night, finally discovering how to save the show-within-a-show, and having fallen in love, Don Lockwood (played by Gene Kelly) heads home. Even though it is raining torrentially, Lockwood doesn't care — even going so far as to give his umbrella to a

passerby. The question now is, how soaked does a walker become if indifferent to the rain? Or, put differently, how wet does Gene Kelly get? From the classical world, we know that Philippides brought joyful news to Athens after the Battle of Marathon, some 26 miles away — collapsing and dying immediately after announcing the victory over the Persians. Had it have been raining, how wet would Philippides have become during his journey?

To answer these questions, we use the familiar structure of the "How fast should you walk…" problem but make the walker/runner more realistically human by means of anthropometric formulas. These we combine with biomechanical models of walking and long-distance running to determine how wet, and how drenched, Gene Kelly and Philippides became. Thus, we have a new take on a well-known problem, one that encourages students to model real-world processes in interdisciplinary ways by blending physics with biomechanics — a problem that is therefore is of pedagogical value as well as being of interest for its own sake.

The Water Absorbed By A Moving Block

To begin, consider the walker/runner as a block of height h, width w, and breadth b. Suppose further that the walker has speed v and walks in vertically falling rain of speed u. In addition, assume that the walker has to cover a distance L to reach home. Assume all such walkers are human sponges, who absorb all the water that falls on them, and that the speed at which they walk is unaffected by the amount of water absorbed. This is the same model employed in determining how fast someone must run in the rain to get least wet.

The top of the (bareheaded) walker has an area wd. If the rain falls with a vertical speed u, then in a time dt, the walker absorbs a mass of rain dm_{TOP} given by Equation (1):

$$dm_{TOP} = (\rho wbu)\,dt, \tag{1}$$

wherein ρ is the density of the rain-air mixture. The total amount of rain absorbed through the top surface is during the journey home of duration $T(= L/v)$ is given by Equation (2):

$$m_{TOP} = \rho wbuT = \frac{\rho wbuL}{v}. \tag{2}$$

The mass of water absorbed by the walker through the front surface in time dt is given by Equation (3):

$$dm_{FRONT} = (\rho hwv)\,dt. \tag{3}$$

The total amount of water absorbed through the front is therefore Equation (4):

$$m_{FRONT} = \rho hwL. \tag{4}$$

The carefree, precipitation-indifferent walker thus absorbs a mass of rain shown by Equation (5):

$$m = \rho Lw\left(h + \frac{bu}{v}\right). \tag{5}$$

A rainfall rate, r, is usually specified in millimeters per hour. In an hour rain of speed u m/s travels a distance $3.6 \times 10^6 u$ millimeters. The density of the air-rain mixture is thus[12] given by Equation (6):

$$\rho = \frac{r}{3.6 \times 10^6 u}\rho_0, \tag{6}$$

where ρ_0 is the density of water. Light rain corresponds to $r = 2.5$ mm/hr, heavy rain has $r = 7.5$ mm /hr. The world record for the most rain to fall in one minute belongs to Unionville, Maryland[13] which on July 4, 1956, experienced 31.5 mm of precipitation in 60 seconds, a phenomenal value of $r = 1{,}890$ mm/hr .

Humanizing The Block

Let us think more about such travelers and "humanize" their cuboidal physiques. That is to say, we recognize that there is a certain subset of normal body proportions — the width of a human being is not, for example, ten times the person's height — and so h, w, and b are not independent parameters.

Mosteller's formula[14] states that the total body surface area of a human being, A, in square meters, is given by Equation (7):

$$A = \frac{\sqrt{Mh}}{6}. \tag{7}$$

There is also a human aspect ratio, α, so that the shoulder width of a human, w, is related to height by Equation (8):

$$\alpha = \frac{w}{h}. \tag{8}$$

As with body mass index, this varies with the person — but it does not vary by much. For an average male, of height 69.1 inches and shoulder width of 17.9 inches, $\alpha = 0.26$. This value is almost constant for people in the 2.5th height percentile to the 97.5th height percentile (0.25 to 0.26). For mathematical simplicity, then, we set it equal to 1/4. (The aspect ratio is approximately the same for women: an average height of 63.2 inches and shoulder width of 15.7 inches has $\alpha = 0.248$.[15])

The total surface area of a cuboidal walker is given by Equation (9):

$$A = 2wh + 2wb + 2bh. \tag{9}$$

Combine this with Mosteller's formula[16], Eq. (7), and the aspect ratio, Eq. (8), to obtain Equation (10):

$$\frac{\sqrt{Mh}}{6} = \frac{h^2}{2} + 2bh\left(1 + \frac{1}{4}\right). \tag{10}$$

This enables us to calculate the best breadth for an ideal humanoid cuboid as given by Equation (11):

$$\frac{\sqrt{Mh}}{3} - h^2 = 5bh. \tag{11}$$

So, solving for b we get Equation (12):

$$b = \frac{\left[\frac{1}{3}\sqrt{\frac{M}{h}} - h\right]}{5}. \tag{12}$$

[As a check, this predicts that a 6′ tall walker with a mass of 80kg (176 lbs) has a breadth b=0.085m and thus a chest measurement ($2b + 2w = 2b + 2h/4$) equal to 1.07m, or about 42 inches.]

The mass of rain absorbed by the walker is given by Equation (13):

$$m = \rho L w\left(h + \frac{bu}{v}\right) = \rho L\left(\frac{h^2}{4} + \frac{u}{v}\frac{bh}{4}\right). \tag{13}$$

So m becomes Equation (14):

$$m = \frac{\rho L}{4}\left(h^2 + \frac{u}{5v}h\left[\frac{1}{3}\sqrt{\frac{M}{h}} - h\right]\right) \tag{14}$$

Walking In The Rain

If walkers do not care about the rain, they will amble along at a natural pace. One model for walking is that the legs behave like a rigid pendulum of length L[17], the time period for which is given by Equation (15):

$$T = 2\pi\sqrt{\frac{2L}{3g}}. \tag{15}$$

While such stiff-legged swinging might seem more fitting to model the walk of the undead in the Zombie Apocalypse, it is a surprisingly good fit for low-speed human walking. As the leg length is approximately half the walker's height[18], we get Equation (16):

$$T = 2\pi\sqrt{\frac{h}{3g}}. \tag{16}$$

Pedometer instructions[19] report that step length is $0.415h$ which, to within 1%, is $\frac{2\pi}{15}h$, and thus we get Equation (17):

$$v = \frac{\sqrt{3gh}}{15}. \tag{17}$$

This predicts, as a check, a walking speed of 0.6 $\mathrm{ms^{-1}}$ (about 1.3 mph) for a 1.8m (6′) tall walker.

The mass of water accumulated by a person strolling in the rain is, by combining Eqs. (14) and (17), given by Equation (18):

$$m = \frac{\rho L}{4}\left(h^2 + \frac{15u}{5\sqrt{3g}}\sqrt{h}\left[\frac{1}{3}\sqrt{\frac{M}{h}} - h\right]\right). \tag{18}$$

To estimate this value, we use meteorological data. The speed of falling rain, u, depends on the size of the raindrops, but a good estimate is approximately 5 m/s[20]. Thus we get Equation (19):

$$\frac{15u}{5\sqrt{3g}} = \frac{15}{\sqrt{3\times 9.8}} = 2.765. \tag{19}$$

To a reasonable level of approximation we have Equation (20):

$$m = \frac{\rho L}{4}\left(h^2 + 2.77\sqrt{h}\left[\frac{1}{3}\sqrt{\frac{M}{h}} - h\right]\right). \tag{20}$$

This is the equation that describes the mass of water absorbed by someone of height h strolling a distance L in rain of density ρ.

To compare these results, we follow Holden *et al.* and consider heavy rainfall, so that r=10 mm/h. During a 100-meter journey the walker absorbs a mass of water equal to Equation (21):

$$m = \frac{1}{72}\left(h^2 - 2.77h^{3/2} + \frac{2.77}{3}\sqrt{M}\right). \tag{21}$$

There is, though, a problem. Namely, the mass of a person is not independent of their height. Hence in medicine, one usually speaks of the body mass index (BMI), as defined by Equation (22):

$$B = \frac{M}{h^2}. \tag{22}$$

Hence[21] m becomes Equation (23):

$$m = \frac{1}{72}\left(h^2 - 2.77h^{3/2} + \frac{2.77}{3}\sqrt{B}h\right). \tag{23}$$

This allows us to look at water absorption based on body type. An underweight person has a BMI of 16; a person in the middle of the normal weight range for their height has a BMI of 21.7; an overweight person has a BMI of 25; and a BMI of 30 or more is the clinical definition of obese. For two walkers of the same height, the one with the larger body mass index will get wetter. This is logical, as the speed at which they walk depends only on their height and is thus the same for both walkers, whereas the person with the higher body mass index will have a larger rain-collecting surface

area. By the same reasoning, for two walkers with the same body mass index, the taller one will become less wet, for their walking speed means they get home far more quickly, thus exposing them to less rain.

Numerically, if we assume a 1.8 m-tall walker (6′) with a body mass index in the middle of the ideal range (21.7), and hence a mass of 70.3 kg, the equation predicts absorption of 0.05 kg of water. This is close to the 0.06 kg calculated by Peterson and Wallis for a walker hustling to get home at a speed of 1 ms^{-1}. Figure 1 presents the mass of water absorbed as a function of height for various values of the body mass index.

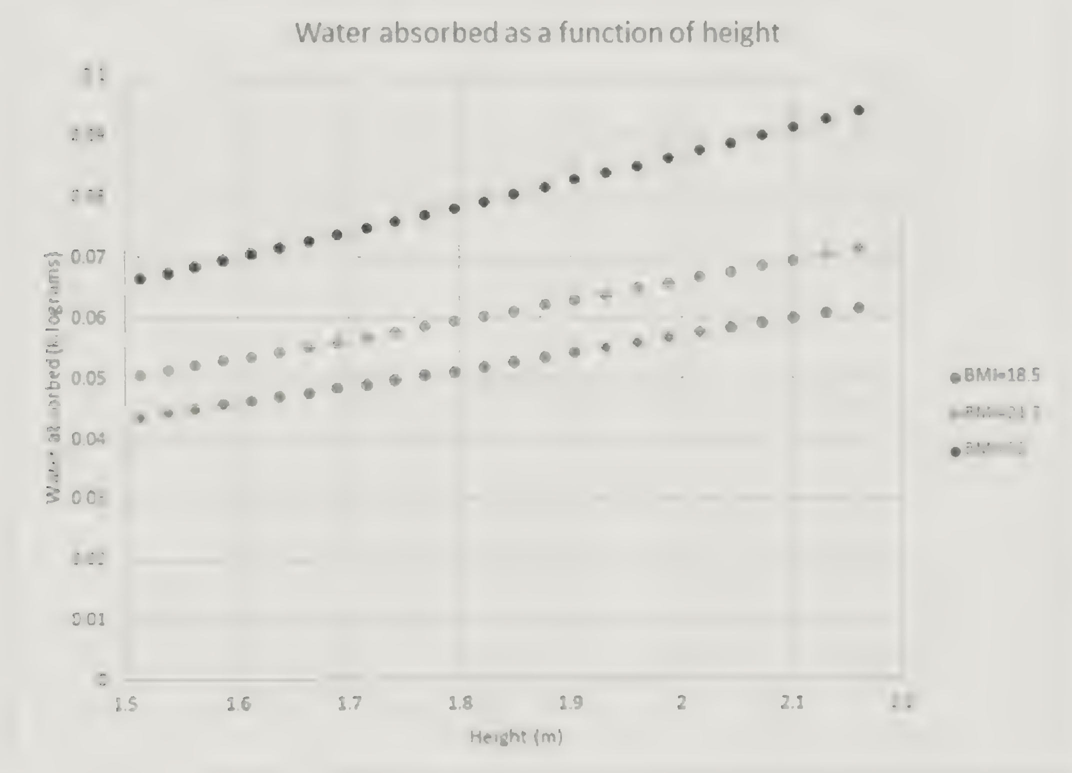

Figure 1

As an example, Gene Kelly was 1.71 meters tall and had a mass of 70 kg[22]. Hence his BMI was 23.94. Thus, as he danced his way home in heavy rain, he absorbed about 0.07 kg of water during the first 100 meters of his journey. In contrast, his co-star, Debbie Reynolds, was 1.57 m tall and weighed 51 kg[23] and thus had a BMI of 20.69. She would have absorbed

a mass 0.057 kg, only 80% of the amount that Gene Kelly did, had she taken part in the song-and-dance number, *Singin' in the Rain*.

This suggests there is another quantity worth considering. Namely, we introduce a drenching factor Δ, which is the ratio of the water absorbed to the walker's weight. Thus we get Equation (24):

$$\begin{aligned}\Delta &= \frac{\rho L}{4}\frac{\left[h^2 - 2.77h^{3/2} + \frac{2.77}{3}\sqrt{M}\right]}{M} \\ &= \frac{\rho L}{4}\frac{\left[h^2 - 2.77h^{3/2} + \frac{2.77}{3}\sqrt{Bh}\right]}{Bh^2}.\end{aligned} \tag{24}$$

The implication is clear. The longer your journey home, or the heavier the rain, the more drenched you become. For two people of the same height, the person of higher mass or larger body mass index is less drenched. For two people of the same mass or body mass index, the taller person is less drenched.

Running In The Rain

Philippides ran from Marathon to Athens to convey news of the Greek victory over the Persians[24]. He would have done so whether the weather be hot or not. What if it had been raining? Again, we can think of him absorbing water rather like a block, but instead of walking, he runs a long distance. The speed of long-distance running is determined, as per Banks, through energy considerations. Philippides generates heat proportional to his kinetic energy. Hence, he produces heat energy E_g governed by Equation (25):

$$E_g = k_g M v^2. \tag{25}$$

Here, k_g is a constant related to heat gain.

From Newton's law of cooling, Philippides loses heat energy E_l through his surface area, so that we get Equation (26):

$$E_l = k_l A = \frac{k_l\sqrt{Mh}}{6}. \tag{26}$$

(The dynamics of weight loss has likewise been modeled by energy loss proportional to human surface area.[25]) A reasonable model for long-distance running, then, is that these two energies must balance, in which case we get Equation (27):

$$k_g M v^2 = \frac{k_l \sqrt{Mh}}{6}, \tag{27}$$

so that v^2 becomes Equation (28):

$$v^2 = \frac{k_l}{6k_g}\sqrt{\frac{h}{M}} = \frac{k_l}{6k_g}\sqrt{\frac{1}{Bh}}. \tag{28}$$

As a plausibility argument, this equation predicts that successful long-distance runners are likely to be relatively short and slight of build. Men's marathon record holder Dennis Kipruto Kimetto is 1.71 m tall, which is below average height, and with a mass of 55 kg has a BMI of 18.8. Sprinter Usain Bolt is 2m tall and has a mass of 93.9 kg, for a BMI of 24.5. These BMIs are at the low and the high end, respectively, of the range of "normal" BMIs.

The mass of water absorbed when running a (long) distance L is, from Eq. (14) and Eq. (28), given by Equation (29):

$$m = \frac{\rho L}{4}\left[h^2 + \frac{u}{5}\sqrt{\frac{6k_g}{k_l}}h\left(\frac{M}{h}\right)^{1/4}\left(\frac{1}{3}\sqrt{\frac{M}{h}} - h\right)\right]. \tag{29}$$

Or, in terms of body mass index, m becomes Equation (30):

$$m = \frac{\rho L}{4}\left[h^2 + \frac{u}{5}\sqrt{\frac{6k_g}{k_l}}h(Bh)^{1/4}\left(\frac{1}{3}\sqrt{Bh} - h\right)\right]. \tag{30}$$

As before, for two runners of the same height, the heavier runner or the one with higher body mass index, will absorb more rain, a consequence of having a larger surface area.

To obtain a numerical estimate, Kimetto's world record is 2:02:57 for the 42.195 km race. Using his data we get Equation (31):

$$v^2 = \left(\frac{42195}{7377}\right)^2 = \frac{k_l}{6k_g}\sqrt{\frac{1.71}{55}}. \tag{31}$$

So that it becomes Equation (32):

$$\frac{k_l}{6k_g} = 185.5. \tag{32}$$

(There are, naturally, some problems in assuming that this number is the same for all athletes and setting its value based on the world record holder. Italy's Stefano Baldini holds the 485th fastest marathon time and has a mass of 162 kg and a height of 1.76 m, which gives a ratio of 180.6. There is variation, then, among elite runners, but the percentage variation is slight.)

Hence, for long-distance road runners in the rain, Eq. (30) and Eq. (32) predict Equation (33):

$$m = \frac{\rho L}{4}\left(h^2 + \frac{h(Bh)^{1/4}\left[\frac{1}{3}\sqrt{Bh} - h\right]}{13.62}\right). \tag{33}$$

Over the course of 100 meters of the race, in rain where r=10 mm/h, the water absorbed is given by Equation (34):

$$m = \frac{1}{72}\left(h^2 + \frac{h(Bh)^{1/4}\left[\frac{1}{3}\sqrt{Bh} - h\right]}{13.62}\right). \tag{34}$$

Figure 2 shows the mass of water absorbed during the course of 100 meters run.

This does not depend appreciably on the body mass index of the runner. This may seem surprising, since for two runners of the same height, the one with lower body mass runs more swiftly and has a lower surface area through which to absorb rain. However, there is a critical height or body mass ratio, for which the term in brackets is zero. This occurs when M is given by Equation (35):

$$M = 9h^3, \tag{35}$$

corresponding to a critical body mass index given by Equation (36):

$$B_{crit} = 9h. \tag{36}$$

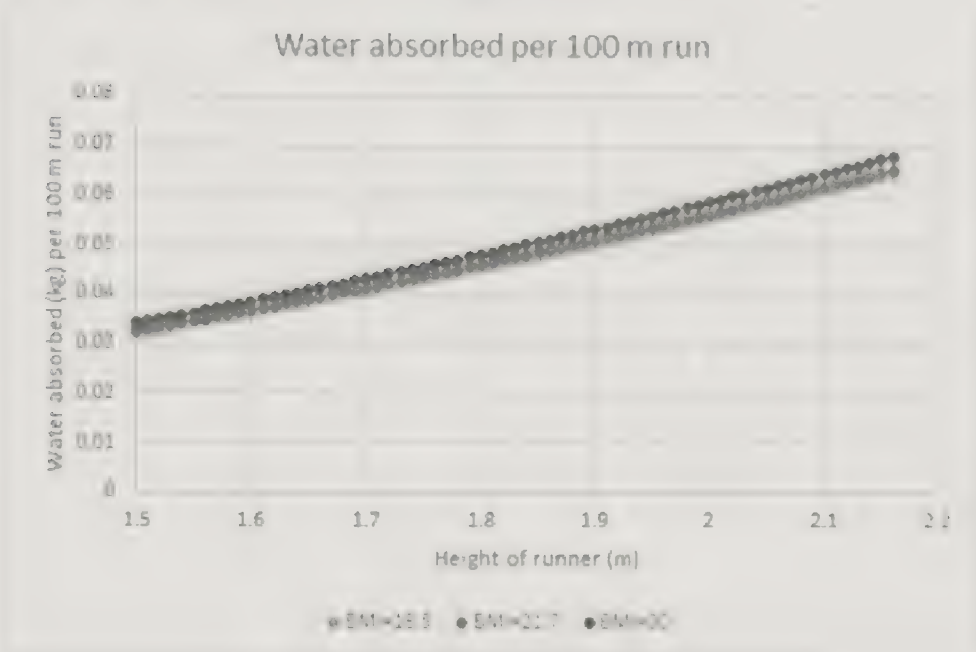

Figure 2

Such a runner absorbs a "critical mass" of water given by Equation (37),

$$m = \frac{h^2}{2}. \tag{37}$$

This is, in essence, the curve shown in Figure 2. Runners with a BMI less than $9h$ will absorb less than this amount; runners with a BMI greater than the critical value will absorb more water. The Center for Disease Control defines the "underweight" category to be a BMI of 16. Hence, a runner of height 1.78 m has a critical BMI of 16.02, and so a slightly underweight runner will be below the critical value. An exceedingly tall runner, of height 2.06m (about 6′ 8″), has a critical BMI of 18.5, which corresponds to a "normal" weight for their height. In other words, most reasonably fit runners will have a BMI close to the critical value and, as a consequence, will absorb an amount of water equal to the critical mass.

The drenching ratio is given by Equation (38):

$$\Delta = \frac{\rho L}{4} \frac{\left[h^2 + \frac{u}{5} \frac{6k_g}{k_l} h \left(\frac{M}{h} \right)^{1/4} \left(\frac{1}{3} \sqrt{\frac{M}{h}} - h \right) \right]}{M}, \tag{38}$$

Or, in terms of BMI it is given by Equation (39):

$$\Delta = \frac{\rho L}{4} \frac{\left(h^2 + \frac{u}{5} \sqrt{\frac{6k_g}{k_l}} h (Bh)^{1/4} \left[\frac{1}{3} \sqrt{Bh} - h \right] \right)}{Bh^2}. \tag{39}$$

Numerically, over 100 meters of the race it becomes Equation (40):

$$\Delta = \frac{1}{72} \frac{\left(h^2 + h (Bh)^{1/4} \left[\frac{1}{3} \sqrt{Bh} - h \right] \right)}{13.62 Bh^2}. \tag{40}$$

Namely, for runners of the same height, the heavier runner is less drenched.

Conclusion

This article has explored how wet people become if, when going somewhere in the rain, they do not care whether they get soaked or not. This is closely related to the well-known problem of how fast to walk in the rain to get least wet. When indifferent to the rain, and thus walking at a natural pace, if two walkers are in the same overall shape, as measured by body mass index, the taller walker will be less wet. Taller walkers have a faster pace, which gets them indoors more swiftly than a slower walk, and this more than compensates for their larger surface area.

Those who run long distances, though, have a different effect. While those of lower body mass index should be able to run more swiftly and have a lower surface area exposed to precipitation, the effect is barely noticeable. The sole determining factor is not whether you are underweight or obese, but how tall you are. Taller runners become wetter. Shorter runners will remain drier than shorter walkers, but extremely tall runners may get wetter than their low body mass index walking counterparts.

[1] B.L. Schwartz and M.A.B. Deakin "Walking in the rain, reconsidered" *Mathematics Magazine* **46**(5) 246–53, 1972 corrects Michael. A. B. Deakin's earlier "Walking in the rain" *Mathematics Magazine* **45**(5), 246–53. The former views the problem as an interesting pedagogical case for mathematics students of minimizing the function $|x|$.

[2] David E. Bell "Walk or Run in the Rain?" *Mathematical Gazette*. **60** No. 413 206–208 (1976).

[3] Mark J. Volkmann's "To walk or run in the rain: A geometric solution" *School Science and Mathematics* **93**(4) 217–20 is suitable for high-school students and introduces the fictional cartoon character Cubo, who could be replaced in modern classrooms by Spongebob Squarepants.

[4] Herb Bailey "On running in the rain" *College Mathematics Journal* **33**(2) 88–92 dissents. He looks at the maxima and minima of the functions involved and thinks that sometimes, even with the wind at one's back, it is best to head home at top speed. Bailey might be the first of those who studied the problem to consider a female walker.

[5] Dank Hailman and Bruce Torrents (a.k.a. Dan Kalman and Bruce Torrence) "Keeping dry: The Mathematics of running in the rain". *Mathematics Magazine* **82**(4) 266–77, 2009.

[6] Robert B. Banks *Slicing Pizzas, Racing Turtles, and Further Adventures in Applied Mathematics*. (Princeton: Princeton University Press, 1999). See chapter 12, "How Fast should you run in the rain", pp 114–122.

[7] J.J. Holden, S.E. Belcher, Á. Horváth, and I Pitharoulis "Raindrops keep falling on my head" *Weather* **50**(11) 367–70.

[8] Thomas C. Peterson and Trevor W. R. Wallis "Running in the rain" *Weather* **52**(3) 93–6, 1997

[9] S. A. Stern "An optimal speed for traversing a constant rain." *American Journal of Physics* **51**(9) 813–818 (1983).

[10] Franco Bocci "Whether or not to run in the rain" *European Journal of Physics* **33**(5) 1321–322, (2012).

[11] Carl E. Mungan and Trevor C. Lipscombe "The Rain-Powered Cart" *European Journal of Physics* **37**(5) 2016 055005

[12] Neglecting the density of the air, which is a mere fraction of the density of water.

[13] Howard H. Engelbrecht and G.N. Brancato "World Record One-Minute Rainfall at Unionville, Marlyand" *Monthly Weather Review*, August 1959, p. 303–306.

[14] R.D. Mosteller "Simplified Calculation of Body-Surface Area," *New England Journal of Medicine* **317**(17) 1987, p. 1098. There are other formulas to model body surface area, but Mosteller's is mathematically the simplest.

[15] See illustration at http://www.learneasy.info/MDME/MEMmods/MEM30008A-EcoErgo/Ergonomics/Ergonomics.html

[16] Mosteller's formula, one might argue, is dimensionally incorrect. This is resolved by considering the 6 in the denominator as a normalizing physical constant, 6 $kg^{1/2}\ m^{-5/2}$, to ensure correct dimensions.

[17] See, for example, Trevor Davis Lipscombe *The Physics of Rugby* (Nottingham: Nottingham University Press, 2009), p. 36.

[18] G J Slater, A J Rice, I Mujika, A G Hahn, K Sharpe, D G Jenkins "Physique traits of lightweight rowers and their relationship to competitive success" *Br J Sports Med* 2005;39:736–741 has measurements of L/h for 62 elite male rowers, with an average value of 0.527, and 45 elite female rowers with a ratio of 0.531.

[19] http://livehealthy.chron.com/determine-stride-pedometer-height-weight-4518.html

[20] As per Holden *et al.*, vide supra.

[21] As with the Mosteller formula, there are dimensional issues. If we regard the denominator as being not M but $1M$, where 1 is a physical constant whose dimensions are $m^2\ kg^{-1}$, the units become correct.

[22] http://starschanges.com/gene-kelly-height-weight-age/

[23] http://www.bodymeasurements.org/debbie-reynolds/

[24] Tradition, and Herodotus (in *The Histories*, 6.105.1), credits Philippides for this feat, and Lucian tells it this way in *A Slip of the Tongue in Greeting*. Plutarch reports, in *The Glory of the Athenians*, that "most historians declare that it was Eucles who ran in full armour, hot from the battle, and, bursting in at the doors of the first men of the State, could only say, 'Hail! we are victorious!' and straightway expired." See Plutarch, "de gloria Atheniensium" in *Moralia* Vol. IV. Translated by Frank Cole Babbitt. (Cambridge: Harvard University Press, 1936) p. 505. For a fuller discussion, see John Haberstroh "Philippides: Famed Marathon Runner?" Presentation, Missouri Valley History Conference, March, 2013, online at https://www.academia.edu/4924439/Philippides_Famed_Marathon_Runner

[25] Carl E. Mungan and Trevor C. Lipscombe "A Physics Model for Weight Loss by Dieting" *Latin American Journal of Physics Education* **6**(3) (2012): 344–346

Bio

Trevor Lipscombe is the director of the Catholic University of America Press. He is the author of "The Physics of Rugby" (Nottingham University Press, 2009); coauthor, with Alice Calaprice, of "Albert Einstein: A Biography" (Greenwood Press, 2005); and editor of the critical edition of Blessed John Henry Newman's novel "Loss and Gain" (Ignatius Press, 2012).

Description of a New Species of Cestode Parasitic Worm from an Indian Scops Owl in Mizoram, India

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Abstract

We report a new genus *Gyrocoelia* Fuhrmann, 1899 from Mizoram, India. In 2007 an Indian Scops Owl (*Ottus bakkamoena*) was procured from a local man in Mizoram, India. On close examination the bird was found to be infected with a new cestode species of the genus *Gyrocoelia* Fuhrmann, 1899. The genus *Gyrocoelia* Fuhrmann, 1899 has only five known species. The newly described species named *Gyrocoelia mizoramensis* is characterized by a globular scolex; rostellum bearing single crown of 128 hooks arranged in 16 loops; multilobulated ovary and a large seminal receptacle differentiating it from the rest of previously described species.

Introduction

The Genus Gyrocoelia was established by Fuhrmann in 1899. Khalil *et al*. (1994) synonymized the genus *Bothriocephalus* Linstow (1906) with *Gyrocoelia*. The type species of this genus is *Gyrocoelia perversa* Fuhrmann, 1899 collected from *Actophilus africanus* from Africa. The other known hosts of the type species are *Himantopus himantopus*, *Hoplopterus spinosus*, *Limosa rufa* and *Vanellus* sp. The following species under the genus *Gyrocoelia* have been synonymized with other species:

1. *G. albaredai* Lopez-Neyra, 1952 and *G. polytestis* Saakova, 1952 have been synonymized with *Infula burhini* Burt, 1939.

2. *G. australiensis* (Johnston, 1910) Johnston, 1912 and *G. kiewietti* Ortlepp, 1937 have been synonymized with *G. coronata* Krefft, 1871.

3. *G. brevis* Fuhrmann, 1900, *G. milligani* Linton, 1927, *G. fausti* Tseng, 1933 and *G. fuhrmanni* Rego, 1968 have been synonymized by Schmidt (1986) with *G. crassa* (Fuhrmann, 1900) Baer, 1940.

Currently the following known species are present under the genus *Gyrocoelia* Fuhrman, 1899:

1. *Gyrocoelia coronata* Krefft, 1871; Host: *Himantopus leucocephalus* from Australia.
2. *Gyrocoelia crassa* (Fuhrmann, 1900) Baer, 1940; Host: *Aegialitis collaris* from Egypt.
3. *Gyrocoelia pagollae* Cable and Myers, 1956; Host: *Pagolla wilsonia* from Puerto Rico.
4. *Gyrocoelia perversa* Fuhrmann, 1899; Host: *Actophilus africanus*, *Himantopus himantopus*, *Hoplopterus spinosus*, *Limosa rufa* and *Vanellus* sp., from Africa.
5. *Gyrocoelia paradoxa* Linstow, 1906; Host: *Aegialitis mongolica* from Philippines.

Our goal is to add a new cestode species discovered in a vertebrate host (*Ottus bakkamoena*) in Mizoram, India.

Material and Methods

During a study tour to collect cestode parasites from vertebrate hosts in Mizoram, India a bird (*Ottus bakkamoena*) with ruffled plumage was procured from a local in North Khawbung district in Aizawl, Mizoram. The bird was examined for parasites in 2007. The bird was euthanized with ethanol in a closed jar following the protocol of Ghosh and Kundu (1999). The protocol of Ghosh and Kundu (1999) is followed as per local standard collection procedure of cestode parasites for infected, sick birds.[1]

A cotton swab of a few drops of ethanol was used for anaesthetization. The necropsy was performed under a stereoscopic microscope. The bird was dissected and the entire alimentary canals were removed and internal organs such as liver, heart, lung, kidney, and urinary

[1] CPCSEA *Guidelines* for Laboratory Animal Facility: GUIDELINES ON THE REGULATION OF SCIENTIFIC EXPERIMENTS ON ANIMALS Ministry of Environment & Forests (Animal Welfare Division) Government of India, June 2007.

bladder were placed into normal saline in petri dishes and examined under a field binocular separately in different petri dishes (Justine *et al.*, 2012).

We found that the bird was infected with two cestode specimens of the genus *Gyrocoelia* Fuhrmann, 1899. The cestode specimens were collected from the intestine of the host, pressed and flattened between two slides, and preserved in 70% alcohol in a glass vial. They were then dehydrated in increasing concentrations of alcohol, stained in alcoholic borax carmine, cleared in xylol, and mounted on slides in Canada balsam (Ghosh and Kundu, 1999). The specimens were studied under a microscope (Magnus MLX-Trinoculor from Olympus, Japan) and camera lucida drawings and photomicrographs were made to describe the species in detail.

Results

We have isolated a new species of *Gyrocoelia mizoramensis* (Figs. 1 and 2) with the characteristics of the genus *Gyrocoelia* Fuhrmann, 1899. The parasites are medium in length and the body consists of scolex, neck, immature, mature, and gravid proglottids. The segments are almost square in shape. Segmentation is craspedote. Immature proglottids are longer than they are broad, while the mature and gravid proglottids are broader than they are long. As the proglottids mature progressively the ratio between the length and breadth decreases, and the proglottids appear to be square. All the measurements given are in millimeters unless otherwise mentioned in the text.

The immature proglottids measure 0.11-0.16 in length and 0.09-0.12 in breadth. The mature proglottids measure 0.12-0.13 in length and 0.26-0.27 in breadth. The gravid proglottids measure 0.16-0.27 in length and 0.31-0.34 in breadth. The parasite measures 19.65-22.13 in length and 0.32-0.34 in breadth.

Head region: The scolex is globular in shape, slightly set off from the neck and measures 0.06-0.15 in length and 0.06-0.13 in breadth. The scolex is provided with four slightly oval and unarmed suckers measuring 0.03-0.05 in length and 0.02-0.05 in breadth. The rostellum is everted measuring 0.06-0.07 in length and 0.1-0.13 in breadth. The rostellum bears a single row of 128 hooks arranged in 16 loops, each loop with eight hooks. There are seven loops on each of its dorsal and ventral surfaces

and one loop on each of its lateral faces. Each hook has a relatively long handle and small guard and blade. The hook is bifurcated. The blade is 0.47-0.51 long. Each loop measures 0.03-0.04 in length and 0.04-0.06 in breadth. The neck is short and broad and measures 0.42-0.63 in length and 0.06-0.07 in breadth.

Testicular region: The testes are round to oval in shape, 27-30 in number, measure 0.03-0.04 in length and 0.04-0.05 in breadth, mostly postovarian while some are present on the two lateral sides of the ovary. The cirrus sac is elongated, slightly oblong and crosses the dorsal osmoregulatory canals. It measures 0.27-0.3 in length and 0.02-0.03 in breadth. The cirrus is unarmed, everted in most of the proglottids and measures 0.2-0.21 in length and 0.02 in breadth. The vas deferens is coiled and thick-walled. There is no external or internal seminal vesicle. The genital pores alternate regularly except in a few proglottids where the genital pores are unilateral. The genital pores are situated in the anterior part of the lateral margin of each proglottid. The genital atrium measures 0.08-0.11 in length and 0.11-0.14 in width.

Uterine region: The ovary lies in the posterior portion of the proglottid. It is single massed, consists of numerous lobes arranged almost fanwise measures 0.1-0.12 in length and 0.16-0.3 in width. There is no ootype. The vagina is a thin tube, arises from the ovary, runs for a very short distance and then dilates into a round seminal receptacle, measuring 0.1-0.12 in length and 0.1-0.14 in breadth in the middle of the proglottid. It then extends as a straight tube from the seminal receptacle and opens posterior to the cirrus sac into the common genital atrium. The uterus appears as a sac but later ruptures and the eggs are entirely released into the proglottids.

Post ovarian region: The vitelline gland is small, compact, and lies posterior to the ovary. It measures 0.4-0.05 in length and 0.07-0.08 in breadth. Each egg is round in shape and has a diameter between 0.02-0.05. The osmoregulatory canals are four in number, two dorsal and two ventral.

Data Summary

Type specimens. Holotype (One specimen in one slide with the Zoological Survey of India Accession number W9943/1; one paratype specimen is also present in the same slide.)

Deposition. Deposited in Platyhelminthes Section, Zoological Survey of India, New Alipur, Kolkata-53, India

Type host. *Ottus bakkamoena*

Site of infection. Intestine

Type locality. Aizawl (Latitude: 23.7271° N, Longitude: 92.7176° E) Mizoram, India

Prevalence.1/2

Etymology. The specific epithet is derived from the name of the state of Mizoram from where it had been recovered.

Discussion

Summarizing the data we note that the present observed species measures 19.65-22.13 in length and 0.32-0.34 in breadth; scolex globular, measures 0.06-0.15 in length and 0.06-0.13 in breadth; suckers four in number, oval, measures 0.03-0.05 in length and 0.02-0.05 in breadth; rostellum measures 0.06-0.07 in length and 0.1-0.13 in breadth , bears a single crown of 128 hooks arranged in 16 loops, each loop carries 8 hooks; neck short; segmentation craspedote; testes 27-30 in number, oval in shape, cirrus sac long and elongated, measures 0.27-0.3 in length and 0.02-0.03 in breadth; cirrus unarmed; genital pores regularly alternate or unilateral; genital atrium deep, measures 0.08-0.1 in length; ovary multilobulated, lies posteriorly, irregular in shape; vagina is a thin tube; seminal receptacle large, round in shape; vitelline gland small, compact, dorsolateral to the ovary; uterus tubular; egg round and diameter is between 0.02-0.05.

The observed species comes closer to *G. pagollae* Cable and Meyers, 1956 in number of testes, presence of a short neck and a fan-shaped ovary. The observed species differs from *G. pagollae* Cable and Meyers, 1956 in not having 66 rostellar hooks; dioecious strobila; spines

in the cirrus; and a V-shaped vitelline gland and absence of seminal receptacle and a genital atrium.

Table 1. A comparative account of the morphological characters of the valid species under the genus *Gyrocoelia* Fuhrman, 1899

Characteristics	***G.coronata*** Krefft, 1871	***G.crassa*** (Fuhrmann, 1900) Baer, 1940	***G.pagollae*** Cable and Myers, 1956	***G.perversa*** Fuhrmann, 1899	***G.paradoxa*** Linstow, 1906	***G.mizoramensis* n.sp.**
Host	*Himantopus leucocephalus*	*Aegialitis collaris*	*Pagolla wilsonia rufinucha*	*Actophilus africanus*	*Aegialitis mongolica*	*Ottus bakkamoena*
Country	Australia	Egypt	Puerto Rico	Africa	Sri Lanka	India
Form	-	Dioecious	Dioecious	-	Male and Female in same strobila	Male and female in same strobila
Body Length (L) and Breadth (B)	-	L=50-62.7 (male) L=100.0 (female)	Male L=30.0 Female L=75.0	L=110, B=1.5-5.5	L= 80-90 B= 3.0	L= 19.65-22.135 B= 0.325-0.34
Scolex Length (L) and Breadth (B)	L= 0.360 B= 0.400	L= 0.210 B= 0.490	B= 0.23-0.34	B= 0.7	B= 0.23	L= 0.065-0.15 B= 0.06-0.135
Suckers Length (L) and Breadth (B)	L= 0.288 B= 0.16	B=0.147-0.175	Shallow B=0.114-0.146	L= 0.33 B= 0.12	B= 0.075-0.09	L= 0.03-0.055 B= 0.02-0.05
Rostellum Length (L) and Breadth (B)	L= 0.2 B= 0.1	L= 0.122 B= 0.073	L= 0.14 B near tip= 0.063-0.067 B near base = 0.045	-	-	L= 0.06-0.07 B= 0.1-0.13
Number of rostellar loops	-	-	-	-	-	16
Number of hooks in each loop	16-17 (Total 100)	40	66	-	78	8 hooks in each loop Total hooks = 128

Length of hook	L= 0.030-0.038	L= 0.040	-	-	L= 0.029	Length of blade = 0.468-0.507
Neck	Present	Absent	Very short	Absent	Absent	Short, broad
Testes Number (N), Length (L) and Breadth (B) ; Genital Pore (G.P)	(N):50	(N):60 -76 L= 0.080 B= 0.038	(N):20-30 G.P:Irregularly alternate, unilateral or Regularly alternate	(N):4 G.P: Irregularly alternate	(N): 3; G.P: Regularly alternate	(N): (27-30) G.P: Regularly alternate
Cirrus sac Length (L) and Breadth (B)	-	Male strobila: L=0.182-0.700 B=0.252-0.900 Female strobila: Cirrus spined	Male strobila L=0.520 B=0.150 Cirrus spined Female Strobila: L=0.765 B=0.207	L=0.75 B=0.20 Cirrus Spined	L=0.4 B=0.16-0.18 Cirrus spined	L=0.27-0.3 B=0.02-0.03 Cirrus not spined
Seminal Receptacle (S.R) Vagina (V)	-	S.R: absent (V): absent	S.R: absent (V):absent	Absent	Present	S.R: L=0.1-0.12 B=0.1-0.14
Genital Atrium (G.A.) Vitelline Gland (V.G) Length (L) and Breadth (B)	-	G.A:Absent; V.G: L=0.112x0.420	G.A:Present, V.G:V-shaped transversely, elongated	G.A:Present	G.A:Present	G.A:Present V.G: L=0.04-0.05 B=0.07-0.08
Uterus	-	Transversely tubular	Transversely tubular with diverticula	-	Tubular	Transversely elongated
Egg	L=0.044 B=0.028	B=0.056-0.059	L=0.059-0.068 B=0.032-0.036	B=0.036	B=0.081-0.047	B=0.02-0.05

Remarks: (–) indicates data not available in original description

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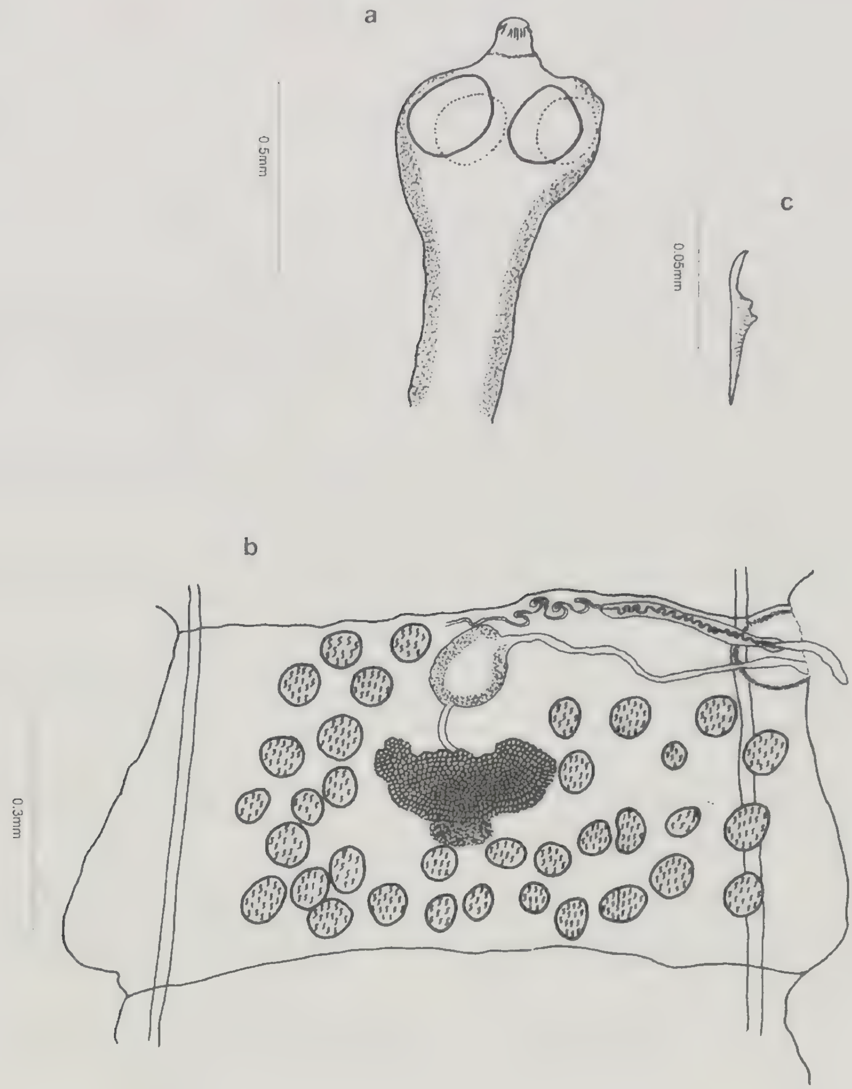

Figure 1. Camera lucida drawings of *Gyrocoelia mizoramensis* n.sp. isolated from *Ottus bakkamoena*
(a) Scolex (b) Mature proglottid (c) Spine

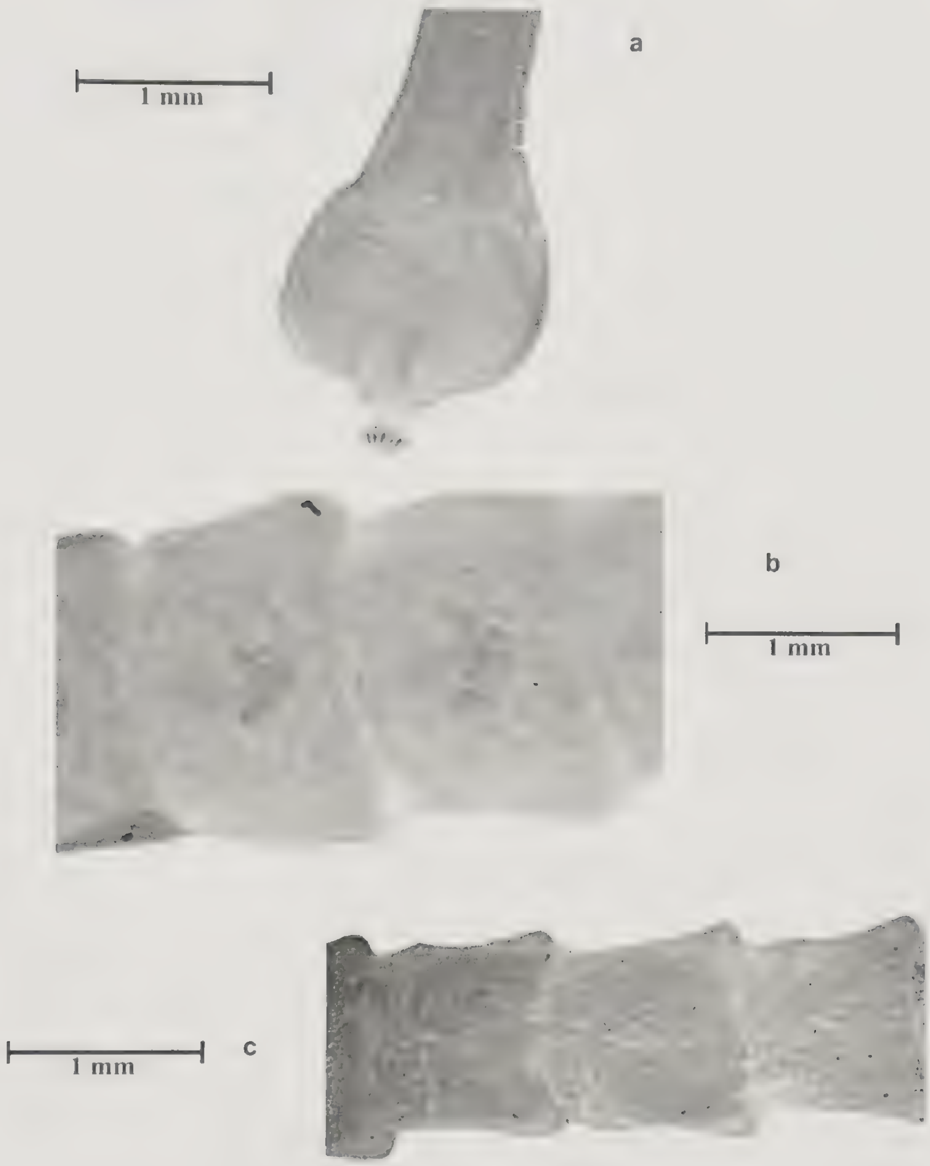

Figure 2. Photomicrographs of *Gyrocoelia mizoramensis* n.sp. isolated from *Ottus bakkamoena*

(a) Scolex (b) Mature proglottids (c) Gravid proglottids

Bios

Dr. Suranjana Banerjee M.Sc., Ph.D. in Zoology is a Senior Zoological Assistant in the Zoological Survey of India. Her field of interest includes research in morphology, taxonomy and systematics of cestodes. She acquired her Ph.D. degree on her work on Taxonomy of Cestodes from Eastern and North Eastern States of India. She has discovered several new species of cestodes from India. Apart from her major field of interest in cestode taxonomy, her other areas of interest include taxonomy of soil nematodes and insects of the order Odonata. She has published more than 15 research papers in national journals.

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